Itanium-Based Solutions in the Manufacturing Market

Analysts: Kara M. Yokley, Earl Joseph II, Ph.D., and Christopher G. Willard, Ph.D.

The Manufacturing Market

The manufacturing market comprises some of the most demanding users of computers in the world. Continuous improvement in innovation rates and time-to-market, product quality, and cost reduction are the sources of competitive advantage. The faster products can be conceptualized, designed, analyzed, and made ready for manufacture, the more competitive the company will be. Manufacturing companies have long been among the most aggressive consumers of high-end computer performance to support this imperative. Manufacturing companies compete heavily on the basis of the degree of automation, speed, and efficiency of their design-through-manufacturing processes.

The need for the highest quality of product design completed in the shortest amount of time possible is found across the entire discrete manufacturing sector. In particular, automotive and aerospace design are two segments where the products are extremely engineering-intensive. Complex and new model designs are required to meet strict safety standards and multiple government regulations. In recent years, manufacturers have begun to stretch the limitations of 32-bit architectures to the breaking point to meet these demanding criteria for success. Among the most critical of their requirements are:

- More real addressable memory and memory architecture bandwidth
- Increased floating-point performance
- Overall system architecture performance and scaling
- Economically viable high-performance computing (HPC) options

Hardware Market for Manufacturing Applications

The size of the discrete manufacturing market segment for technical servers was $1.05 billion in 1999 and represents 18.6% of the overall technical computing server market (see Table 1).

In 1999, Windows NT-based servers represented 6% of the server market, while Unix/Linux servers accounted for 93% (other OSs = 1%). By

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5 Speen Street • Framingham, MA 01701 • Phone (508) 872-8200 • Fax (508) 935-4015

2004, Windows NT is projected to grow to 10% of the technical server market, with Unix/Linux holding 89%.

Table 1
Technical Computing Server Market, 1998–2004 ($M)

	1998	1999	2000	2001	2002	2003	2004	1998–2004 CAGR (%)
Mechanical design and drafting (CAD)	172	206	217	230	237	241	240	3.1
Mechanical design and engineering analysis (CAE)	752	841	960	1,081	1,190	1,315	1,438	11.3
Total manufacturing revenue	924	1,047	1,177	1,311	1,427	1,556	1,678	9.9
Total technical market revenue	4,796	5,617	6,278	6,885	7,385	7,990	8,567	8.8
Manufacturing applications as a % of the overall market	19.3	18.6	18.8	19.0	19.3	19.5	19.6	

Source: IDC, 2000

For the technical server market, IDC tracks two manufacturing subsegments: 1)mechanical design and drafting (CAD) and 2)mechanical design and engineering analysis (CAE). These two subsegments combined are expected to grow to $1.68 billion by 2004. The mechanical design and engineering analysis subsegment is projected to grow the fastest at 11%. The overall manufacturing segment growth rate of 10% is slightly higher than the overall technical market growth rate of 9%.

In terms of workstations, the growth of NT-based systems is expected to be much higher than Unix-based workstations. In 1999, sales into CAD and CAE accounted for $1.04 billion. By 2004, IDC expects that number to be closer to $2.5 billion.

Currently, Windows NT-based workstations are used mostly for CAD tasks, which are less computationally intensive than CAE tasks. Engineering analysis end users use Unix-based systems because of the 64-bit capabilities — more addressable memory and increased floating-point precision. By entering the 64-bit processor market, Intel can offer solutions that will satisfy demands of CAE users. This is important because although CAE is still a fairly small market for Windows NT-based workstations, it is one of the fastest-growing segments, with a revenue compound annual growth rate (CAGR) of 29% from 1999 to 2004.

Growth is expected to be strongest at lower price points initially and in clustered systems. Itanium-based systems have been announced from most of the current workstation and server hardware vendors,

and many manufacturing customers have already been benchmarking beta systems.

Software Market for Manufacturing Applications

Within the manufacturing design automation segment, CAD applications comprise the majority of revenues, but product information management (PIM) is the fastest-growing segment. In 1999, the PIM market grew 38% to $826 million. IDC expects strong growth to continue in this segment. By 2004, revenue from the sale of PIM applications will account for more than $2.5 million.

PIM provides integrated product development (IPD) teams and supply chain partners with the software tools required to access product, process, and procurement data and to electronically manage and communicate the product data throughout its life cycle. IDC includes product data management (PDM), component and supplier management (CSM), model translation and healing, standalone product configurators, and visualization software among PIM applications.

The use of PDM systems to back up design and engineering collaboration will increase, leading to a resurgence in enterprise-level federated data systems. PDM systems will be needed to supply data to real-time design systems as well as real-time and asynchronous collaboration via visualization and teleconferencing software.

The total market for mechanical engineering packaged applications grew 6.6% to reach $3.7 billion in 1999. IDC forecasts an 11.2% CAGR for the mechanical engineering packaged application market from 2000 to 2004.

Independent software vendors (ISVs) continued to dominate the market as a source of applications over system vendors (SVs). U.S.-based ISVs garnered a 67% market share in 1999; internationally based ISVs had a 19% share. U.S.-based SV and internationally based SV market shares fell from previous years to 5.0% and 8.8%, respectively. Usage of mechanical engineering applications was heaviest in North America and Western Europe, with 41% and 36% shares, respectively.

In 1999, 32-bit Windows operating environments from Microsoft nearly caught up with varieties of Unix as the most prevalent operating environments for these types of applications. The top 10 mechanical engineering packaged application vendors in 1999 by overall market share were the following (these market shares are across 13 different operating system [OS] environments):

1. PTC — 22.9%

2. Dassault Systemes — 11.8%

3. Unigraphics Solutions — 8.9%

4. SDRC — 8.5%

5. Autodesk — 4.8%

6. HP/CoCreate Software — 4.0%

7. MSC Software — 3.7%

8. MICROCADAM — 3.4%

9. Aspect Development — 2.1%

10. ANSYS — 1.4%

Note: The above mechanical engineering applications market analysis estimates total license revenue for application packages that automate mechanical engineering (i.e., CAD, CAE, CAM, and PIM). This revenue includes initial and add-on licenses, maintenance fees, and service fees for like functionality (e.g., related revenue flowing through service bureaus and application service providers (ASPs) and charged per transactions or via subscriptions, rental, or similar means).

Manufacturing ISV Application Example

MSC Software develops and sells some of the most popular manufacturing software packages, including NASTRAN, PATRAN, MARC, and DYTRAN. MSC also has Linux solutions for the HPC manufacturing market. It is writing its own kernels for any OS that will run on IA-64, including Linux and Windows 64. MSC.NASTRAN has already been ported to run on IA-64.

MSC believes that Linux will be a key driver of Itanium usage in the manufacturing market because traditional Unix users will feel more comfortable moving to another flavor of Unix rather than the Windows OS. MSC also believes that IA-64 will give Linux a second chance with mainstream businesses — hence MSC's aggressive Linux strategy.

MSC.NASTRAN, MSC.MARC, and MSC.DYTRAN will see the largest performance boosts of all of MSC's software products from Itanium. Among the largest benefits:

- Floating-point performance
- Memory bandwidth
- Improvements to chipset (I/O is important because they write terabytes of data due to the large size of models.)

MSC feels that the largest benefit of IA-64 will be its price/performance and the ability to reach lower price points. The company expects it to bring a higher level of capability to a larger audience. Ultimately, businesses using CAE software on IA-64 will benefit because they can get products to market faster without breaking the bank on hardware.

Itanium's Technical Computing Capabilities

Several applications areas within the manufacturing segment — including MDA, CAD, and design and simulation analysis — have historically placed some of the greatest performance demand on computers. In technical computing, the solution of one problem inevitably leads to a set of new and more complex issues (e.g., early computers were used to create automotive body designs, which then led to crash analysis and then to advanced airflow analysis to reduce drag and increase fuel economy). The complexity of the next generation of problems drives requirements for more powerful and complex computational tools.

Advanced manufacturing applications, like other traditional technical applications, begin with mathematical models of physical parts, manufacturing tolerances, characteristics of various materials, and so on. Then designers simulate the effects of different physical forces, interrelations between moving parts, airflow, deformations due to normal operations and during crashes, and so forth on the model in an effort to determine how the modeled object will behave in the real world. The result of this analysis would aid in developing better product designs.

This modeling and simulation process leads to a number of requirements for computer processor architectures in areas such as floating-point performance, memory performance, and support for large data sets. This section briefly reviews these requirements and provides an overview of Intel's strategy for meeting these requirements with its Itanium processor.

Floating-Point Performance

Floating-point performance equates to raw speed — how many adds, multiplies, divides, and so forth the system can perform in a given amount of time. Floating-point performance is a function of the ability to perform floating-point operations in parallel and the cycle time for the processor to execute these operations. This can be calculated as the number of floating-point functional units that can issue a result per clock, multiplied by the cycle time of the processor. On the Itanium this number is increased by functional units that can perform two operations in a single clock period. The Itanium is configured with two floating-point functional units known as floating-point multiply add calculations (FMACs). These units can multiply two values and add that result to a third value. (Multiply/add operations are at the heart of many technical calculations such as matrix multiplies.) Thus, an Itanium running at 800MHz can produce four floating-point results a clock cycle for a peak 64-bit performance rating of 3.2 billion floating-point operations per second (GFLOPS).

The Itanium architecture also includes two 32-bit FMACs that are tuned for 3D graphics performance and can each perform four single-

precision floating-point operations per cycle for a 6.4GFLOPS single-precision rating on an 800MHz processor.

The above analysis is considered the "peak" performance of the processor in that it represents a best-case scenario in which the functional units are always busy. Intel has incorporated a number of features in the Itanium architecture that help to maximize sustained performance. These include:

- **Pipelined functional units.** Arithmetic operations generally require more than one machine cycle to complete. A pipelining scheme is used to allow the FMACs to produce results each cycle. The arithmetic operations are broken into a set of independent steps, each requiring one machine cycle to complete.

- **Dual-function arithmetic units.** A secondary benefit of the dual-function FMAC strategy is that the processor is able to use both functional units even when the distribution of adds and multiplies is biased toward one operation. For example, if a section of code performs only additions, both FMACs can be employed on the task.

- **Large register sets.** The Itanium is configured with 128 floating-point registers. The more data that is directly available to the FMACs, the less likely a functional unit will stall due to lack of data. In addition, the large register sets provide a buffer for the memory system to move data in and out of memory.

- **Internal parallelism.** The Itanium can issue up to six instructions per cycle, in a combination of four integer arithmetic/logical operations, two load/store operations, two floating-point operations, and three branch operations. The ability to execute multiple operations not only keeps as much of the processor working as possible but also allows for the pre-fetching of data from memory into registers and cache, thus minimizing processor stalls due to data unavailability. The processor also enables a load-double pair instruction to feed the processor with a balance of a memory operation per floating-point operation.

- **Compiler support for parallelism.** The Itanium was designed to allow for closer coordination between the processor and the compilers that generate the machine instructions for the processor. Three instructions are bundled along with a template field where the compiler can provide "hints" to the hardware on the interactions between the instructions. These hints are used by the processor to schedule instructions in real time and for pre-fetching of data for future operations.

Memory Performance — Keeping the Processor Fed

A large fraction of manufacturing problems and applications are memory-bound rather than compute-bound — that is, the speed of

the memory system ultimately determines the speed of the application. Ideally, the memory system will move data in and out of the processors fast enough to keep the floating-point functional units from stalling for lack of data.

Memory performance is measured in terms of both latency (i.e., how many cycles it take to get data from memory to the processor and, in so doing, fill cache lines for subsequent data requests) and bandwidth (i.e., how many bytes of data can be moved in a clock cycle). Current systems architectures use memory hierarchies to address both latency and bandwidth issues. Hierarchies consist of a main memory and several layers of caches, and they trade off memory speed for size and cost. A small, fast cache is located "close" to the registers and functional units and can supply data at roughly the rate the processor calls for it. Data is staged through successive levels of cache, with each level holding more data and running somewhat slower until main memory is reached.

At the base of the Itanium hierarchy is main memory, which can vary in size and speed depending on individual system configurations and the system bus (or chipset) that connects the Itanium processors to memory and I/O subsystems. The processor can read or write 16 bytes of data to/from memory every bus cycle; thus, for a 133MHz bus, the memory bandwidth is 2.1GBps. The 460GX chipset, the chipset that supports the Itanium processor, also has the ability to write an additional 2.1GBps from I/O to memory, for a total of 4.2GBps memory and I/O bandwidth. The Itanium processor uses a 4MB L3 (level 3) cache for access to large data structures such as texture maps for digital content applications. The L3 cache communicates with the 96KB L2 cache and the register file, moving data at 12.6GBps (16 bytes per 800MHz system clock) and with a 24 cycle latency for floating-point numbers. The L2 cache feeds data directly into the floating-point registers at a rate of 32 bytes of data per clock tick and with a 9 clock latency.

Support for Large Data Sets

The Itanium processor is Intel's first 64-bit architecture. As such, it opens up new opportunities for Intel-based systems in technical markets. Manufacturing problems grow in two directions:

1. First, more advanced analysis of current problems requires more detailed models, thus requiring larger, more detailed data sets.

2. Second, next-generation problems tend to involve more complex product designs or attempt to model more complex phenomena, and thus require large data sets to describe the problems.

The requirement to operate on larger data sets generates in turn requirements for computer systems to provide larger real and virtual memories. A computer system's addressable memory is usually determined by the size of its integer or address registers. 32-bit architectures

can directly address 4GB of either real or virtual memory. Beyond this limit, some form of memory segmentation must be employed.

64-bit architectures can in theory address about 10^{19} bytes of data. The important point is that 64-bit systems allow computer systems to expand memory virtually indefinitely without having to resort to some form of segmentation. This large memory space has two major advantages for technical users:

1. **Increased applications performance.** A major bottleneck for many technical applications is the time spent in swapping data between disk and memory — access to data on disk is roughly an order of magnitude slower than memory. The large memories provided by 64-bit systems — up to 1.8TB on the Itanium (the 460GX enables 64GB of physical memory; other original equipment manufacturer [OEM] systems can enable larger memory) — allow applications to keep more of the problem set in memory, thus reducing the amount of time spent reading and writing disk files. In the best case, the entire problem can be moved into memory, transforming an "out of core" problem into an "in core" problem.
2. **Simplified programming model.** The larger real and virtual memories afforded by 64-bit architectures enable applications developers to design programs without having to divide the problem into smaller, memory-sized segments and then develop a code to manage those segments.

Future Market Drivers

Future manufacturing applications will require larger memory sizes and increases in performance of 10 times to 1,000 times today's levels in order to achieve major breakthroughs, such as:

- Creating multidisciplinary simulations and analyses that incorporate structures, chemistry, thermals, and computational fluid dynamics (CFD) into a single analysis
- Eliminating building costly prototypes and test models and going directly from the computer design to manufacturing
- Incorporating simulation and analysis of the manufacturing process into the initial product designs
- Designing products with high durability and quality (e.g., cars that last for 150,000 miles without any failures)
- Producing full aircraft simulations, eventually replacing wind tunnels

Many larger-scale manufacturing solutions today are based on Unix servers. Linux running on Itanium provides an easy transition for manufacturing applications by providing strong price/performance

combined with a Unix environment. Customers can select either single-node Linux servers or cluster multiple nodes for greater capacity. Some customers may experiment with running manufacturing problems across multiple nodes in an Itanium cluster, but most will run each problem on a single node and frequently on a single Itanium processor.

Emerging Trends

Several emerging trends gained strength in 1999. We believe these trends will help define future directions for technical computing markets and, in particular, the manufacturing sector.

Web-Based Applications

Although commercial Web applications have captured the spotlight in the past few years, the technical computing community has continued to expand its use of the technology. 1999 saw the emergence of next-generation Web-based technical applications as vendors made the Internet and Internet services an integral part of their product offerings. Web-based applications that IDC is tracking for their potential as future market drivers include:

- **Intranet infrastructure-based applications.** One feature of the Web is that it provides an instant WAN infrastructure and applications-level communications standards. We believe that users are moving to take advantage of this infrastructure in such areas as design chain management, integration of product data, better communications with suppliers, and researching product component alternatives and availability.
- **Application service providers (ASPs).** 1999 saw significant interest in opportunities for ASPs in technical computing. Under this model, users would send data over the Web to be processed using a specific application on a service provider's system. The service provider assumes responsibility for all computer hardware and software to run the application and charges on a per-use basis. This business model was widely discussed during the year, with several vendors indicating that efforts are in progress to bring technical ASP offerings to market. ASPs may make remote computing service bureaus a success by taking advantage of the wide-scale usage and trust in the Web.

Engineering Portals

Web-based services that provide virtual networks for storing and shared data and for supporting collaborative engineering efforts are entering the market. These services allow for the creation and operation of virtual teams that may be brought together to work on specific projects for limited amounts of time. Teams may be made of engineers from a single company or from multiple organizations. Engineering

portals also provide an instant infrastructure for companies attempting to integrate geographically dispersed design teams.

For these Web-based engineering initiatives to come to fruition, a powerful, scalable, and reliable infrastructure is needed. ASPs are using 64-bit-capable systems to make engineering portals and other Internet/intranet applications available.

IDC Analysis

Itanium is the first iteration of Intel's EPIC architecture. Although it is not the only 64-bit architecture in the manufacturing server market, it does provide interesting solutions for the manufacturing market:

- Companies' ability to acquire high-performing servers at a more reasonable price level — expanding the use of CAE
- Floating-point performance
- Scalability and clustering
- Memory addressability (average job size today is 2GB to 16GB and growing at nearly Moore's law rates)

Many manufacturing server applications will quickly move to Itanium-based servers as most HPC technical vendors have already announced Itanium-based server solutions. It is also expected that a number of Linux- and NT-based clustered server solutions will be used in manufacturing applications. The move to true 64-bit applications will take a while, although most manufacturing ISVs will help lead the way and already have 64-bit versions of their software running on Unix-based servers. However, transitions to new architectures are never easy and rarely happen overnight.

One very important aspect that will help Intel in this transitional period is that it has forged many partnerships with hardware, OS providers, and ISVs. With so many third-party vendors already showing support for Itanium, end users can be assured that if they decide to use IA-64-based solutions, they will have plenty of options from which to choose.

NORTH AMERICA

Corporate Headquarters
5 Speen Street
Framingham, MA 01701
508-872-8200

IDC Canada
36 Toronto Street, Suite 950
Toronto, Ontario, Canada M5C2C5
416-369-0033

IDC Irvine
18831 Von Karmen Ave, Ste 200
Irvine, CA 92612
949-250-1960

IDC Mtn. View
2131 Landings Drive
Mountain View, CA 94043
650-691-0500

IDC New Jersey
120 Wood Ave South, Suite 509
Iselin, NJ 08830
732-632-9222

IDC New York
2 Park Avenue
Suite 1505
New York, NY 10016
212-726-0900

IDC Texas
100 Congress Ave, Suite 2000
Austin, TX 78701
512-469-6333

IDC Washington
8304 Professional Hill Drive
Fairfax, VA 22031
703-280-5161

ASIA/PACIFIC

IDC Asia/Pacific (Hong Kong)
12/Floor, St. John's Building
33 Garden Road
Central, Hong Kong
852-2530-3831

IDC Asia/Pacific (Singapore)
71 Bencoolen Street, #02-01
Singapore 189643
65-226-0330

IDC Australia
Level 4, 76 Berry Street
North Sydney, NSW 2060, Australia
61-2-9922-5300

IDC China
Room 611, Beijing Times Square,
88 West Chang'an Avenue, Beijing,
P.R. China, 100031
86-10-8391-3456

IDC (India) Limited
Cyber House
B-35, Sector 32 - Institutional
Gurgaon - 122002, Haryana, India
91-124-6381673 to 80

IDC Japan
10F The Itoyama Tower
3-7-18, Mita Minato-ku
Tokyo 108-0073, Japan
81-3-5440-3400

IDC Korea Ltd
Suite 704, Korea Trade Center
159-1, Samsung-Dong, Kangnam-Ku
Seoul, Korea 135-729
82-2-55-14380

IDC Malaysia
Suite 13-03, Level 13, Wisma KiaPeng
No. 3, Jalan Kia Peng
50450 Kuala Lumpur, Malaysia
6-03-2163 3715

IDC New Zealand
Level 7, 246 Queen Street
Auckland, New Zealand
64-9-309-8252

IDC Philippines
7F, SEDCCO 1Bldg
Rada Street Corner
Legaspi Street
Legaspi Village
Makati City, Philippines
632-894-4808

IDC Taiwan Ltd.
10F, 31
Jen-Ai Rd, Sec 4,
Taipei 106, Taiwan, R.O.C.
886-2-2731-7288

IDC Thailand
27 Soi Charoen Nakorn 14
Charoen Nakorn Road, Klongtonsai
Klongsan Bangkok 10600, Thailand
66-2-439-4591-2

IDC Vietnam
37 Ton Duc Thang Street
Unit 1606
District-1 Hochiminh City Vietnam
84-8-910-1235

EUROPE, MIDDLE EAST, AND AFRICA

IDC Austria
c/o Loisel, Spiel, Zach Consulting
Mayerhofgasse 6
A-1040 Vienna, Austria
43-1-50-50-900

IDC Benelux (Belgium)
29 Avenue Louis Gribaumont
B-1150 Brussels, Belgium
32-2-779-46-04

IDC Benelux (The Netherlands)
A. Fokkerweg 1
1059 CM Amsterdam
The Netherlands
31-20-669-2721

IDC Central Europe (ECE)
Male Namesti 13
Praha 1 110 00, Czech Republic
420-2-2142-3140

IDC Central Europe (Germany)
Nibelungenplatz 3, 11th Floor
60318 Frankfurt, Germany
49-69-90502-0

IDC Central Europe (Switzerland)
Niederlassung Züerich
WTC, Leutschenbachstrasse 95
CH - 8050 Züerich
Switzerland
41-1-307-1000

IDC Egypt
39 Iraq Street
Mohandesseen, Cairo, Egypt
20-2-336-7355

IDC France
Immeuble La Fayette
2, Place des Vosges, Cedex 65
92051 Paris la Defense 5, France
33-14-904-8000

IDC Hungary
Bajcsy-Zsilinszky út. 57
Building 3, Rooms 103-104
H-1065 Budapest, Hungary
36-1-153-0555/ext. 165, 166

IDC Israel
4 Gershon Street
Tel Aviv 67017, Israel

IDC Italy
Viale Monza, 14
20127 Milano, Italy
390-2-284-571

IDC Nigeria
House 2, 'C' Close
403 Road, 4th Avenue
New Extension, Festac Town
Lagos, Nigeria
234-1-883585

IDC Nordic (Denmark)
Jagtvej 169B
DK-2100 Copenhagen, Denmark
45-39-162222

IDC Nordic (Finland)
Jarrumiehenkatu 2
FIN-00520
Helsinki, Finland
358-9-8770-466

IDC Nordic (Sweden)
Box 1096 Kistagången 21
S-164 25 Kista, Sweden
46-8-751-0415

IDC Poland/ProMarket
Wrobla 43
02-736 Warsaw, Poland
48-22-644-4105

IDC Portugal
Av. Antonio Serpa, 36 Piso 9
1050-027 Lisbon
Portugal
351-21-796-5487

IDC Russia
c/o PX Post, RDS 186
Ulitsa Zorge 10
Moscow 125525
Russian Federation
7-501-929-9959

IDC South Africa
c/o BMI-TechKnowledge
3rd Floor, 356 Rivonia Blvd.
PO Box 4603, Rivonia, 2128
South Africa
27-11-803-6412

IDC Spain
Ochandiano, 6
Centro Empresarial El Plantio
28023 Madrid
34-91-7080007

IDC Turkey
Tevfik Erdonmez Sok. 2/1 Gul Apt.
Kat 9D; 46 Esentepe
Istanbul, Turkey
90-212-275-0995

IDC U.K.
British Standards House
389 Chiswick High Road
London W4 4AE
United Kingdom
44-20-8987-7100

LATIN AMERICA

IDC Miami
Latin America Headquarters
5301 Blue Lagoon Drive
Suite 490
Miami, FL 33126
305-267-2616

IDC Argentina
Trends Consulting
Rivadavia 413, 4th Floor, Suite 6
C1002AAC, Buenos Aires, Argentina
54-11-4343-8899

IDC Brasil
Alameda Ribeirão Preto, 130 cj 41
01331-000 São Paulo
SP Brazil
55-11-253-7869

International Data Corp. Chile
Luis Thayer Ojeda 166 Piso 12
Providencia, Santiago 9, Chile
56-2-231-0111

IDC Colombia
Carrera 40 # 103-78
Bogota, Colombia
571-533-2326

IDC Mexico
Select - IDC
Av. Nuevo Leon No. 54 Desp. 501
Col. Hipodromo, Condesa
C.P. 06100 Mexico, D.F.
52-5-256-1426

IDC Venezuela
Calle Guaicapuro
Edif. Torre Seguros Alianza
Piso 6, Ofc. 6-D, El Rosal
Caracas 1060, Venezuela
58-2-951-3270

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